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DEVELOPMENT OF BANANA PEDUNCLE FIBRE REINFORCED POLYESTER COMPOSITE FOR STRUCTURAL APPLICATIONS

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Abstract

Plant-based natural fibers are presently used as reinforcement in polymer composites, replacing the expensive and non-renewable synthetic fibers such as glass for structural application. This work investigated the potentials of using waste Banana peduncle fibers (BPF) as reinforcement for polyester composites for structural applications. The composites were produced by varying the BPF from 5 to 20wt%. The density, mechanical properties and microstructure of the composite were examined. The results showed that lower weight structural components can be produced with this composite. 181.5% improvement in the tensile strength and 56.63% increases in the flexural strength were obtained over that of the unreinforced polyester. The higher values of tensile and flexural strength obtained at 20wt% addition is within the acceptable limit for outdoors application and roofing sheets production. Improvement of 40.12% was obtained for the impact energy at 20wt%. It has been established that BPF can be used to improve the mechanical properties of polyester.

Keyword: Banana peduncle (BPF), Polyester, Mechanical properties, Density and Microstructure.

1. Introduction

Recent studies indicate that plant-based natural fibers can be used as reinforcement in polymer composites, replacing the expensive and non-renewable synthetic fibers such as glass, because of their potential for recyclability (Mohanty, Misra, & Drzal 2001; Okafor, Okafor, Joseph & Ihueze 2018). Plant fibers can serve as excellent reinforcing agent for plastics because of their moderately high specific strength and stiffness which is used as reinforcement materials in polymeric resin matrices to make useful structural composite materials (Ihueze, Oluleye, Okafor, Obele, Abdulrahman, Obuka & Ajemba 2017; Joseph, Mattos, Toledo, & Thomas 2001). Cellulose-based natural fibers are potential resources for making low cost composite materials. Cellulosic fillers of a fibrous nature have been of greater interest, because they would give composites with improved mechanical properties compared to those containing non-fibrous fillers. Lignocellulosic fibers like jute, sisal, coir, and pineapple have been reportedly used as reinforcements in polymer matrix (Joseph & Thomas 1993).

Sreekala, Kumaran, Joseph, Jacob and Thomas (2000), measured the tensile properties of untreated and modified fibers, such as tensile strength, Young's modulus and elongation at break. Many of the modifications decreased the strength properties due to the breakage of the bond structure, and also due to the disintegration of the non-cellulosic materials. Abdullah and Ahmad (2003), have prepared coconut fibre reinforced polyester composite (CFRPC) by incorporating sodium hydroxide and silane treated coconut fibre inside unsaturated polyester resin. Dicron, a phosphate based flame retardant was added to CFRPC system to enhance its fire performance

Venkata and Venkata (2008) reported on the mechanical behaviour of hybrid epoxy based composites using Kevlar and glass fibers as constitutive. The structural composites developed performed excellent in tensile, bending and impact tests comparatively with their counterparts. Earlier, Dutra (2000), reported on impact performance of a mixture of polypropylene and carbon fibers as reinforcing elements into an epoxy matrix. They argued on the improved properties of hybrids in comparison with CF based composites.

Wambua, Ivens and Verpoest (2003) worked on the replacement of glass fibers with natural fibers .The mechanical properties of the different natural fibre composites were tested and compared. Kenaf, hemp and sisal composites showed comparable tensile strength and modulus results. To increase research in this area of natural fibres motivated this new research which is on the development of polyester/banana peduncle fibres composites. Banana peduncle is a by-product of the banana industry. Peduncle is the stalk that supports the inflorescence and attaches it to the rhizomes and the individual fruits, is separated from the cluster at the packing house and discarded. A few studies investigated value addition to the peduncle by using it as a raw material for paper production, fiber boards, and fertilizers, and as an additive for burger patties.

2.0 Material and methods

2.1 Material

Peduncles of bananas were collected from a Banana seller at Enugu, in Enugu State Nigeria (see Plate1a).
The banana peduncle was conventionally subjected to water retting process to extract the fibres from the peduncle. The peduncle was chopped at the inter-node and crushed with a mallet. This process was to facilitate the process separating the fibre strands. The chopped and crushed peduncles were then soaked in a tank and left to soak for 3 weeks. Water retting enhanced the production of more identical and high quality fibres. After soaking for three week, the peduncle was processed in a roll-out machine to separate the fibres (Plate 1b). The separated fibres were washed carefully using running tap water to remove any impurities. Finally, the banana peduncle fibre was sun-dried for a few days to remove the maximum moisture from the fibre. The fibres were weighed daily to ensure that they have completely dried and achieved a homogenous weight of dried fibre. Colour change within the fibre indicated the loss of moisture.

Plate 1a. Banana peduncle

Plate 1b. Banana peduncle fibre (BPF)

2.2 Methods

The vinyltriethoxysilane (VTS) and 3-aminopropyl triethoxysilane (APTES) solutions were Prepared at concentrations (3 wt-%) by adding the required type of silane (VTS or APTES) into the mixture of water and ethanol (20/80 wt-%), and then stirring, using a glass rod until completely dissolved. (Mohammad, Kuncoro, Mujtahid & Djoko 2018). The fibres were treated with these VTS and APTES solutions for a period of 3hours. The Polyester resin was converted from a liquid to the solid state by adding a Hardener, Methyl Ethyl Keton Peroxide, symbolized by (MEKP) in the form of a transparent liquid was added to unsaturated *polyester resin* at room temperature. An accelerator, cobalt naphthalene was used to increase the rate of curing. BPF of 0, 5, 10, 15 and 20wt% were produced.

The basic method of determining the density of composite samples was by measuring the mass and volume of the sample used. The tensile strength of the composites was measured using a computerized Testonometer in accordance with the ASTM D 3039-76 standards at a cross head speed of 10 mm/min. Three (3) specimens from each sample were tested. The three point bend test was carried out to obtain the flexural properties of all the composite samples using the Testonometer. The tests were performed as per the ASTM D 2344-84 standards with the cross-head speed of 10 mm/min.

Charpy impact test was used to determine the impact energy of the composite materials. The test was carryout according to ASTM D256 standard using Advanced Pendulum Impact Tester Instron- IT 9050- type testing machine. To observe the surface morphology, scanning electron microscopy (SEM) (model: LEO 435 VP, Carl Zeiss SMT) was used. The samples were first carbon coated using a sputter coater.

3.0 Results and Discussions

The results obtained for the physical and mechanical properties are shown in Table 1

Table 1: Results of the physical and mechanical properties

Composition of composites	DENSITY	W.A %	T.M	T.S	F.M	F.S	IMPACT EVERY 5/MRK
0wt%BPF	1.2	0.98	247.05	5.47	1172.93	20.22	4.903
5wt%BPF	1.1	0.99	357.8	10.24	1770.7	22.12	5.88
10wt%BPF	0.98	1.2	371.4	12.84	2416.93	25.0	6.08
15wt%BPF	0.89	1.25	358.6	12.94	2794.74	31.0	6.66
20wt%BPF	0.86	1.45	389.6	15.4	2522.57	31.67	6.87

W.A=water absorption, TM=tensile modulus, TS=tensile strength, FM=flexural modulus, FS=flexural strength.

3.1 Density of the Composites

The results obtained for the composites are shown in Figure 1 and (Table 1). From Figure 1, it was observed clearly that as the wt% BPF increased in the polyester matrix, the density of the composites produced decreased. The decreases in the density of the composites could be attributed to the fact that the BPF has lower density than the polyester. This results shows that lower weight structural components can be produced with these composites. Similar observation was observed in the work of Hassan, Aigbodion, & Patrick 2012; Ihueze, Obiafudo & Okafor 2017).

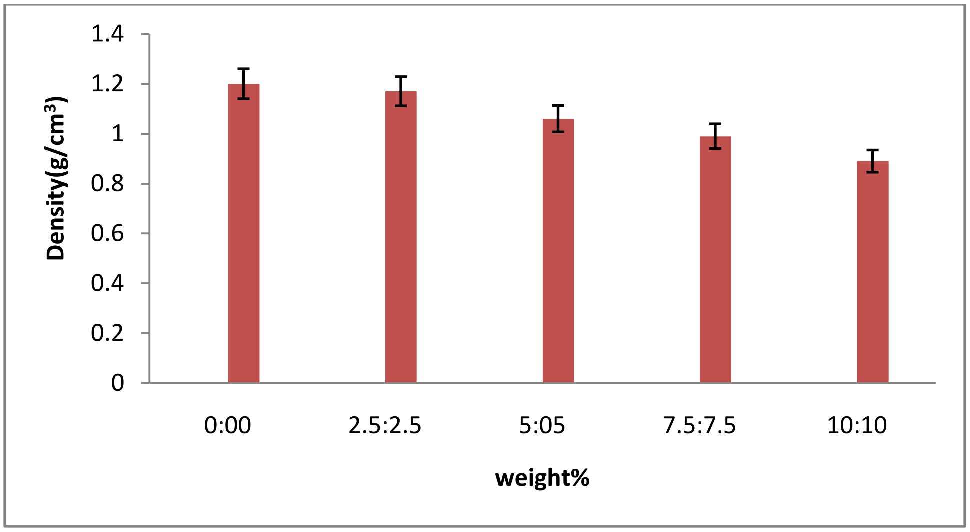

Figure 1: Variation of Density with weight % BPF,

3.2 Tensile Properties

The results of the force-extension curves obtained for the developed composites are displayed in Figure 2, while the tensile strengths and modulus are shown in Figures 3-4 and Table 1 respectively. From Figure 2 it was observed that the composites have the largest area under the force versus extension plot. This resulted to the tough properties of BPF than the polyester. In all the results, the samples slightly increased in the proportional region until the maximum force is obtained in the materials. Beyond this point resulted to sharp decreased to point zero.

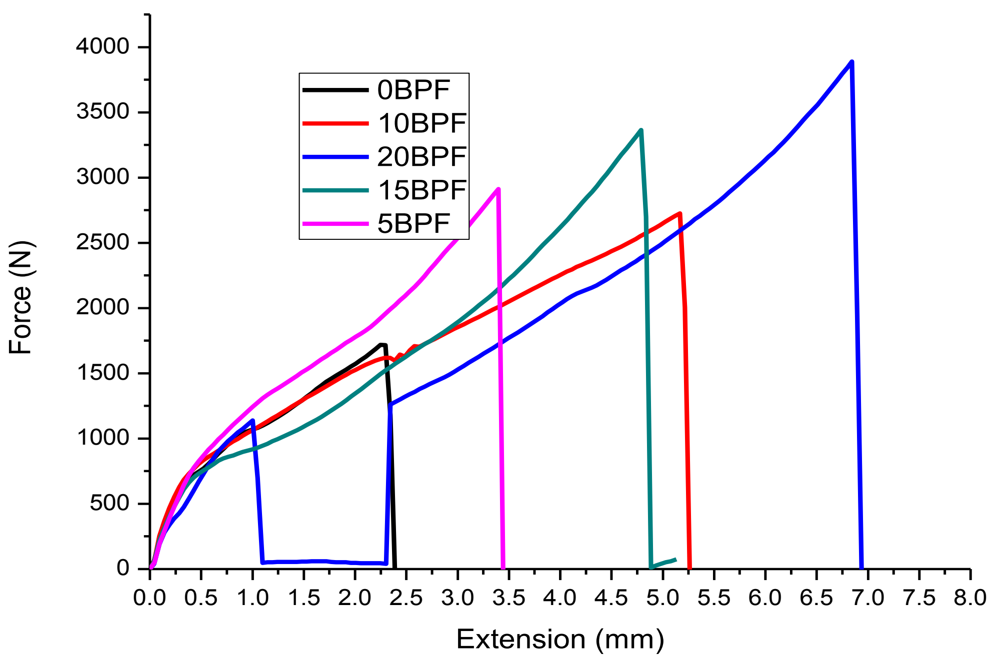

Figure 2: Variation of Force with Extension for composites produced with BPF addition

Figure 3 showed that the tensile modulus of the composite sample increased significantly after reinforcement with BPF. For example tensile modulus of 247.05 and 389.6MPa were obtained for the polyester and composite at 20wt% BPF respectively (see Table 1). This shows that the stiffness of polyester was enhanced with the addition of BPF.

The presence of polar group in the matrix (polyester groups) may have contributed to electrostatic adsorption between polyester and reinforcement. This phenomenon is driven by different charges acting on matrix or reinforcement surfaces. This mechanism will strengthen the polymer-reinforcement interface. It will hold them together and increase their resistance to deformation. This helped in increasing the composites modulus. The fairly uniformity of reinforcement distribution has efficiently hinders the chains movement during deformation. This mechanism will increase the stiffness of the composites as well as tensile strength. (Ihueze, Obiafudo & Okafor 2016; Akash, Venkatesha & Sreeniva 2017).

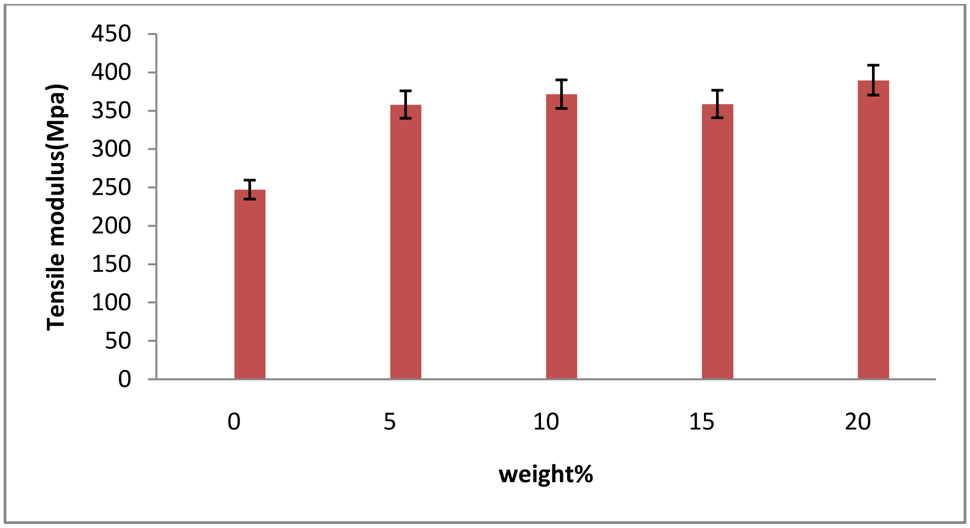

Figure 3: Variation of Tensile modulus with weight % BPF addition

The tensile strength increased as the wt% BPF addition increased. This indicated that addition of BPF improves the load bearing capacity of the composites. Similar observations had been reported by Akash et al (2017) for other filler reinforced polymer composites. In addition, the developed composites deform less until maximum load, which gives a higher tensile strength.

The tensile strength of the composites increased maximum values 5.47 and 15.4MPa at 0wt%BPF and 20wt%BPF respectively. This value gave 181.5% improvement in the tensile strength. The values obtained are within the limit for the production of roofing sheets. The tensile strength obtained at these maximum points is due to the stability of the reinforcement to support stresses transferred from the polymer matrix. Similar results are obtained in the work of Akindapo, Binni, & Sanusi (2015) & Mohammad et al (2018).

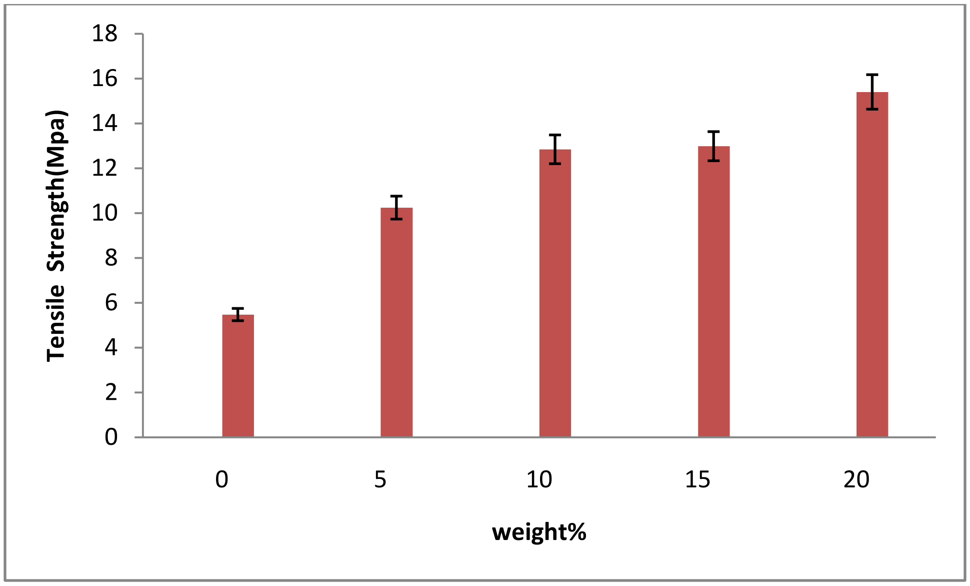

Figure 4: Variation of Tensile strength with weight %BPF addition

3.3. Flexural Strength

Figure 5 show the curve of force versus deflection, while Figures 6-7 and Table 1 displayed the flexural modulus and strengths. It was obvious observed in Figure 5 that the addition of BPF enhanced the force before deformation and deflection. This result is similar to the observation of the tensile properties discussed above. The higher the region under the deflection means the materials have a higher toughness.

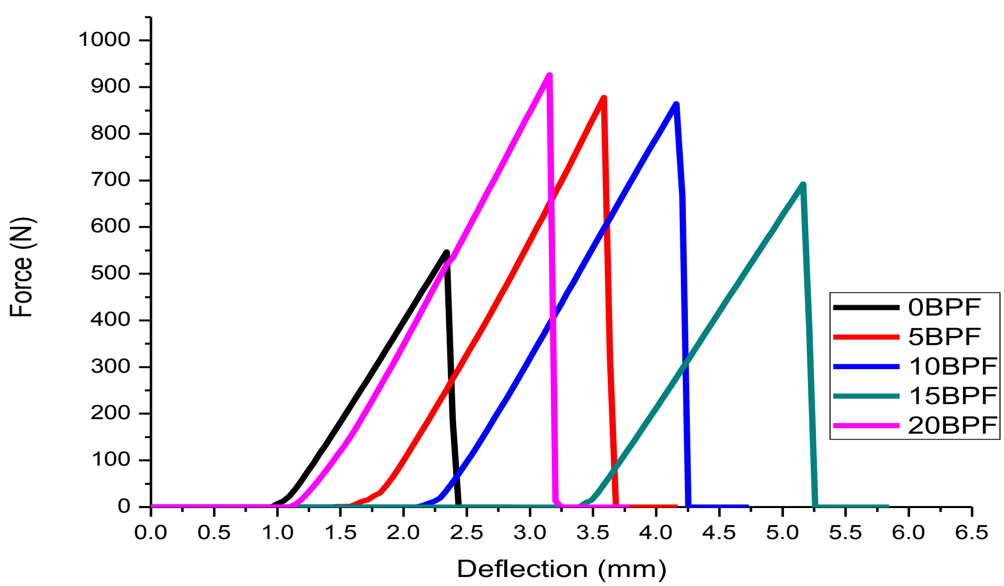

Figure 5: Variation of Force with Deflection for composites produced with BPF addition

Flexural strength and modulus of the composites were obtained experimentally from the bend tests. It is interesting to note that flexural strength increases with increase in BPF. For example flexure strength of 20.022N/mm^2 was recorded for the polyester matrix and 12.45 and 31.67 at 20%wtBPF (see Table 1 and Figures 6-7).

The uniform arrangement of BPF increases the reinforcement-polyester matrix interaction and consequently increases the ability of the composite to restrain gross deformation of the polyester matrix under bending (Mohanty *et al* 2001), 56.63% increases in the flexural strength was obtained over that of the unreinforced polyester. The higher values of flexural strength obtained at 20wt% addition are within the acceptable limit for outdoors application and roofing sheets production. (Akindapo *et al* 2015).

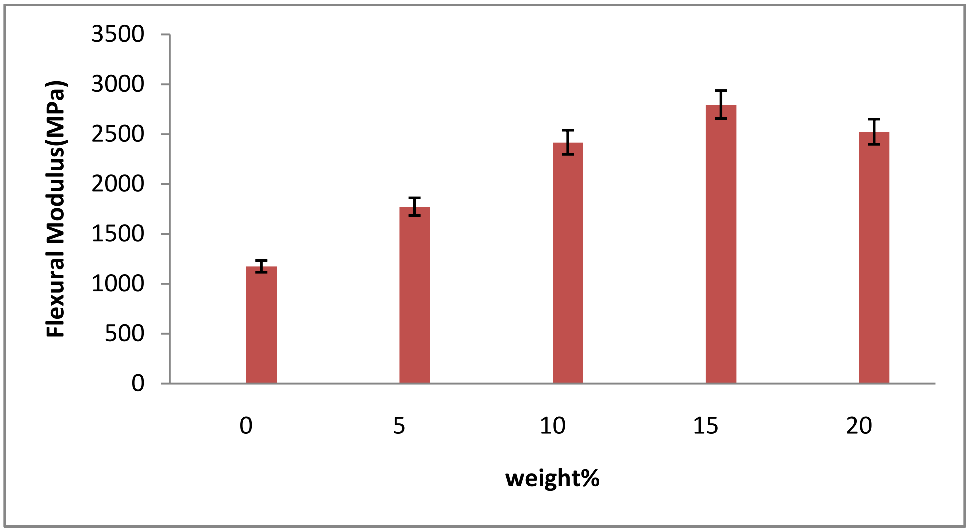

Figure 6: Variation of Flexural modulus with weight % BPF addition

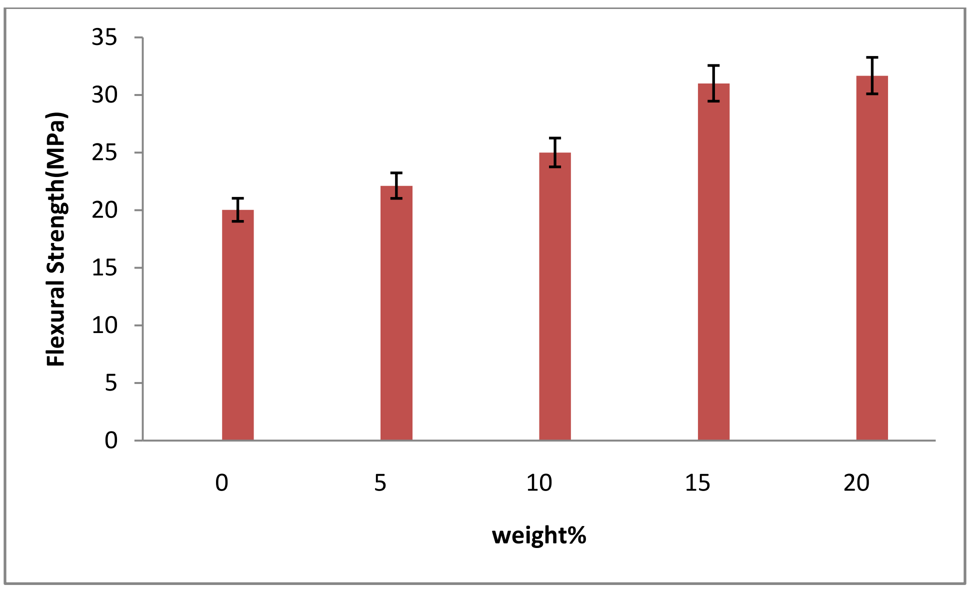

Figure 7: Variation of Flexural strength with weight %BPF addition

3.4. Impact Energy

The impact energy values of the composites recorded during the impact tests are given in Figure 8 and Table 1. From Figure 8 it was observed that the impact energy of the composites slightly increased with increases in BPF addition.

The increases in impact energy as the BPF addition increase could be attributed to the facts that increasing BPF loading increased deformability of a rigid interface between the BPF and polyester matrix. The impact energy of 4.903 and 6.87J/mm^2 were obtained at 0wt%BPF and 20wt%BPF addition respectively. Improvement of 40.12% was obtained for the impact energy at 20wt%. The value is within acceptable limit roofing sheets production. (Okafor & Godwin 2014; Akindapo *et al* 2015).

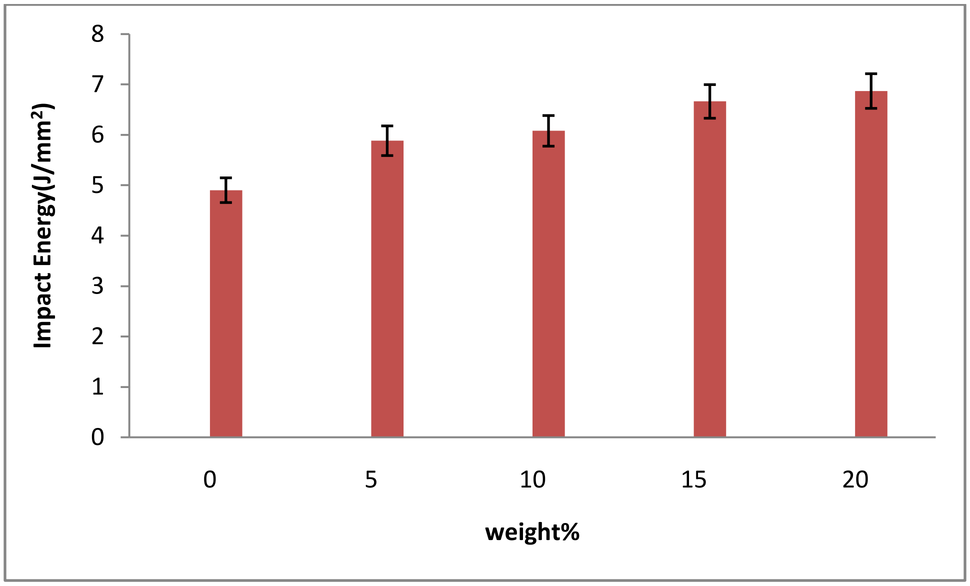

Figure 8: Variation of impact energy with weight % BPF addition

3.5 Microstructure

Microstructure was used to shows the interfacial bonding and dispersion of the BPF in the polyester matrix. The fracture morphologies of the polyester and its composites produced with BPF are show in Figures 9-11. Morphological analysis using Scanning Electron Microscope (SEM) clearly showed differences in the morphology of the polymer composites when compared with the morphology of the polymer matrix separately (see Figure 9 with Figures 10-11). The microstructure clearly shows that when the BPF was added to the polyester matrix, morphological change in the structure took place.

The microstructure of the polyester matrix revealed chain of lamellae and interlammeller amorphous structure with linear boundaries between adjacent spherulites boundaries (see Figure 9).

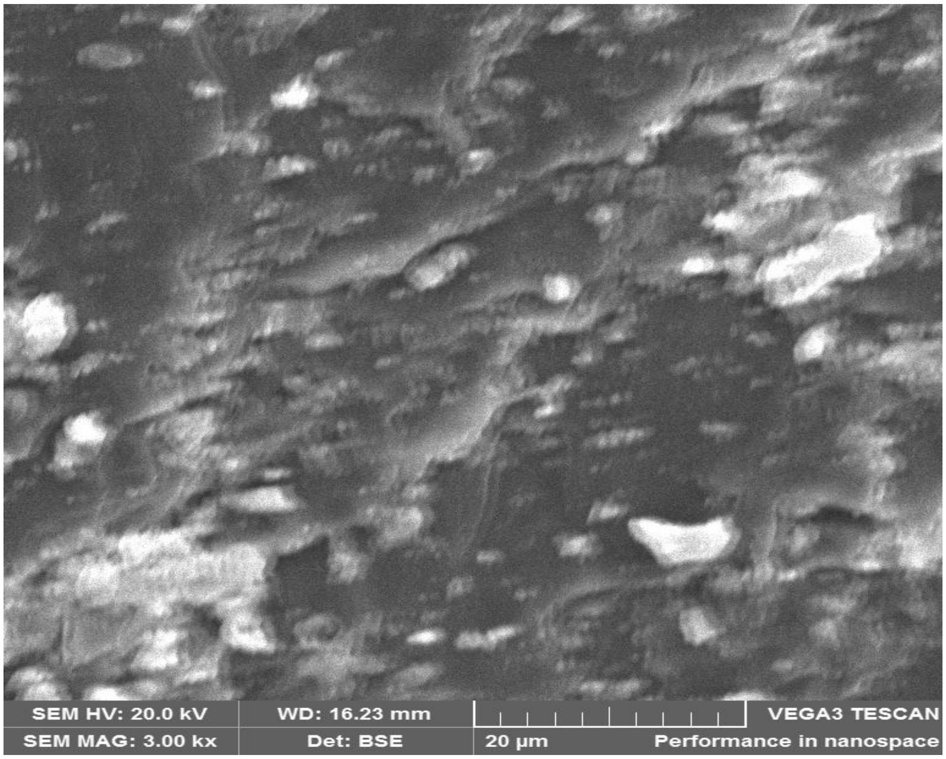

Figure 9: SEM image of the polyester matrix

Figures 10-11 revealed the SEM image of the composites produced with BPF, it was observed that little amounts of agglomerates were obtained. This microstructure obtained for BPF plays a role in increasing the tensile and flexural strengths as discussed above.

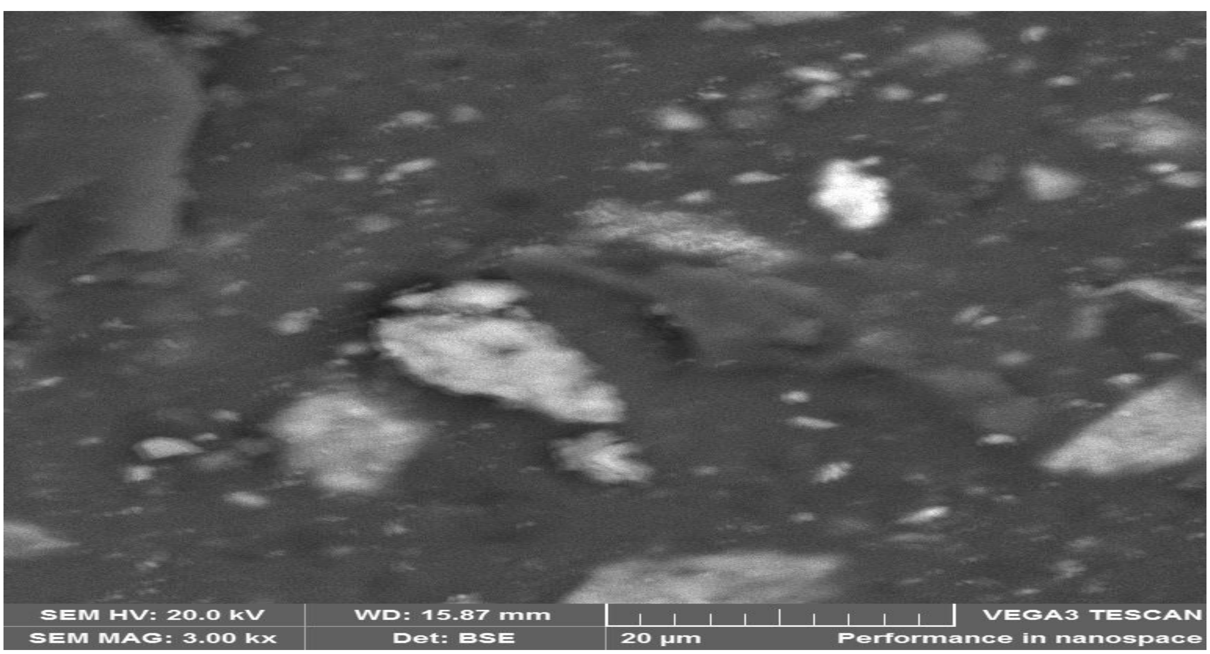

Figure 10: SEM image of the polyester matrix with 5%BPF

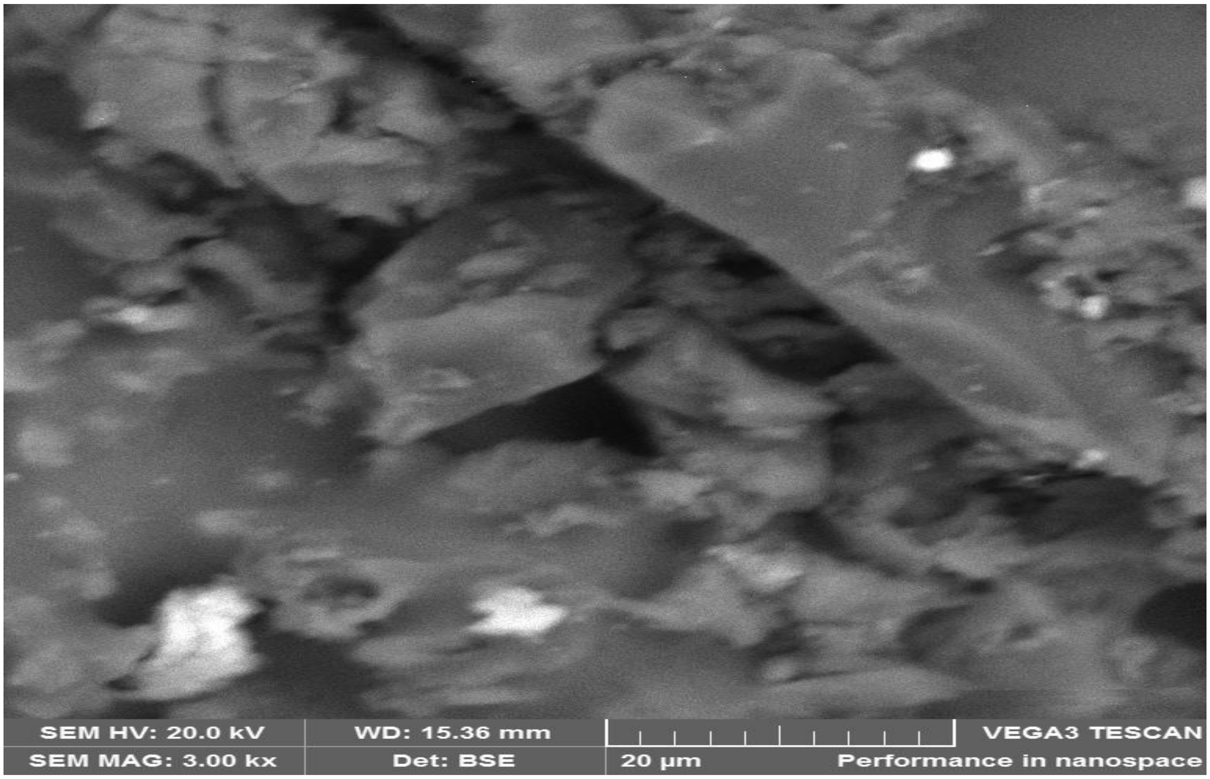

Figure 11: SEM image of the polyester matrix with 20%BPF

4.0. Conclusion

The work centered on improving the properties of polyester by reinforcing it with BPF to enhance its structural application like in roofing sheet production. From the results and discussion the following deductions can be made:

1. The result of the density shows that lower weight structural components can be produced with these composites.
2. Tensile modulus of 247.05 and 389.6MPa were obtained for the polyester and composite at 20wt% BPF
3. The tensile strength of the composites increases from 5.47 to 15.4Mpa at 0wt%BPF and 20wt%BPF respectively. This value gave 181.5% improvement in the tensile strength.
4. 56.63% increases in the flexural strength was obtained over that of the unreinforced polyester. The higher values of flexural strength obtained at 20wt% addition are within the acceptable limit for outdoors application and roofing sheets production.
5. Improvement of 40.12% was obtained for the impact energy at 20wt%.
6. It has been established that BPF can be used to improve the mechanical properties of polyester.

5.0 Recommendation

It is recommended that further research work should be done on the design and production of structural materials like sample roofing sheet especially on the manufacturing process and finishing process. This could result in improved mechanical properties of the composite leading to reduction in the cost of production. It is also recommended that further work in the following identified areas be done

1. The use of other molding processes apart from hand layup techniques in the manufacturing process
2. The use of other types of polymer such as vinyl ester etc. or other locally available bonding agent should be investigated and compared with the obtained results from this work.
3. There is the need to study how environmental and biochemical pollution could affect the structural materials produced with this composite and how to control them.

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